LA-UR-21-24641
Approved for public release; distribution is unlimited.

Title:	Instabilities and Turbulence Studies on the Vertical Shock Tube
Author(s):	Desjardins, Tiffany
Intended for:	Internal presentation
Issued:	2021-05-13

Los Alamos
NATIONAL LABORATORY

Instabilities and Turbulence Studies on the Vertical Shock Tube

Tiffany Desjardins
P-2, Applied & Fundamental Physics

May 13, 2021

EXTREME FLUIDS

John Charonko

Adam Martinez

Tiffany Desjardins

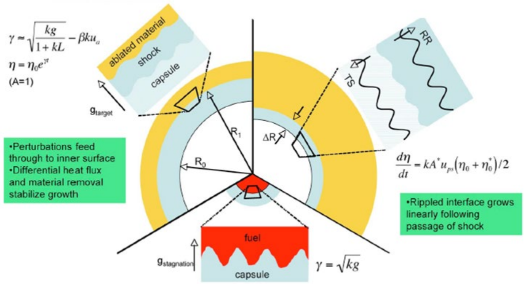
Kyle Hughes

Dominique Fratantonio

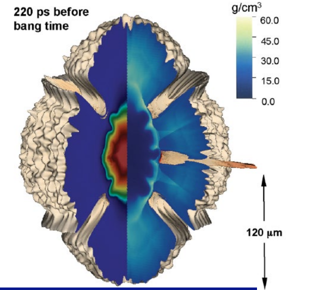
Erin Connor

Antonio Martinez

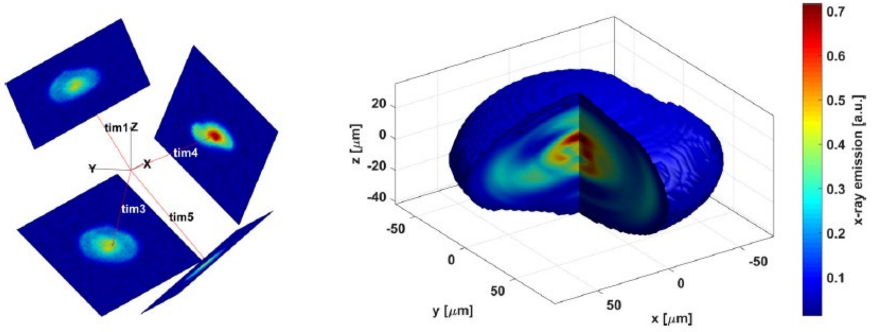
Experimentally we find initial conditions affect how materials mix and turbulence develops, and these effects are not well captured in our simulations



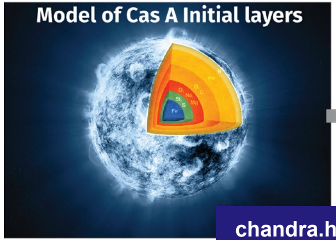
Loomis, E., *et al.* Phys. Plasmas 17 (2010)

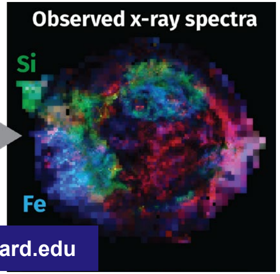


Clark, D.S, *et al.* Physics of Plasmas 23 (2016)



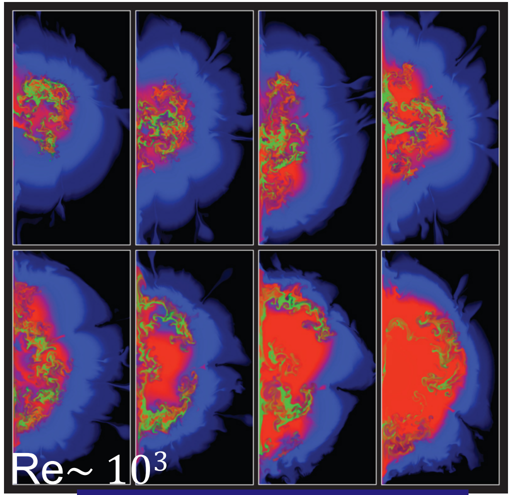
Volegov, P. L., *et al.* Journal of Applied Physics, 122 (2017)





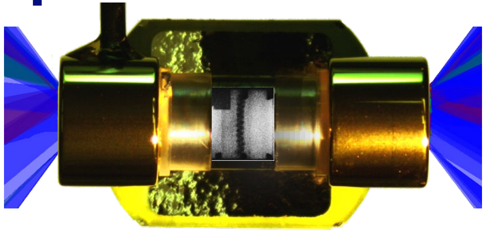
chandra.harvard.edu

Simulation of IC effects on chemical structure

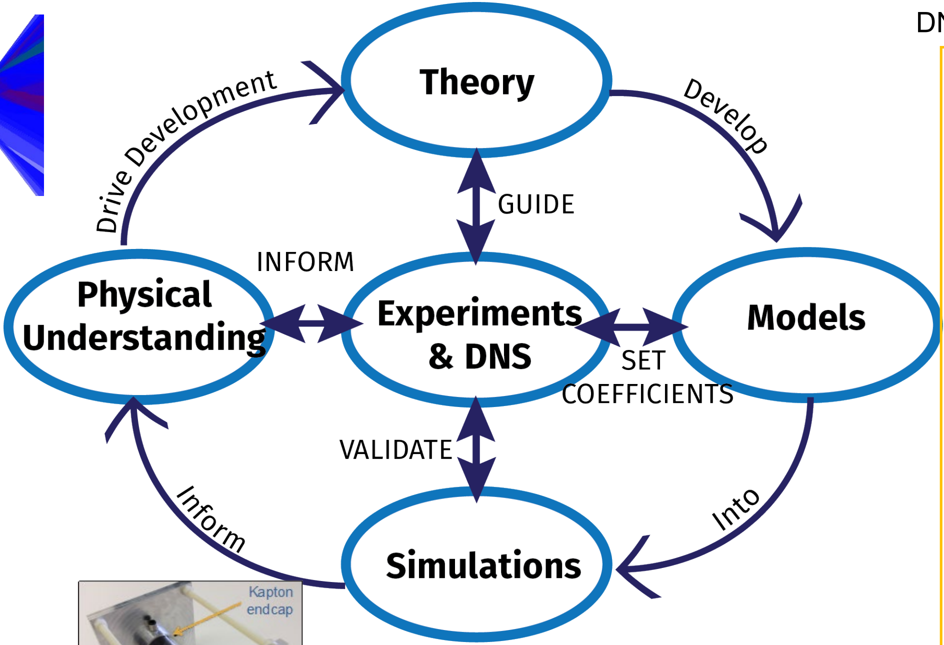


D Kasen *et al.* (2009) *Nature*

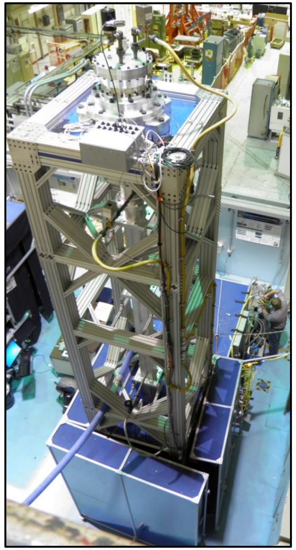
LANL is exploring this problem over a range of physical lengths and energy scales, from low-energy density (fluid) experiments to high-energy density (plasma) experiments



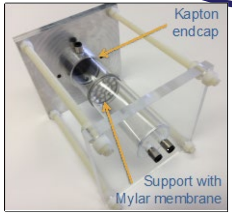
NIF Multi-interface work



DNS=Direct Numerical Simulations



Vertical Shock Tube (VST)



pRad turbulence experiments: MaRMITE

Lab-scale low-energy density experiments explore targeted physical processes to improve theoretical understanding, and help validate model implementation in codes

Full understanding LANL's variable-density turbulence model, BHR, requires measurements of correlated velocity and density components

Favre-averaged Reynolds Stress, R_{ij}

$$\frac{\partial\left(\bar{\rho}\tilde{R}_{ij}\right)}{\partial t}+\left(\bar{\rho}\tilde{u}_k\tilde{R}_{ij}\right)_{,k}=\left[a_i\bar{P}_{,j}+a_j\bar{P}_{,i}\right]-\bar{\rho}\left[\tilde{R}_{ik}\tilde{u}_{j,k}+\tilde{R}_{jk}\tilde{u}_{i,k}\right]+\frac{C_\mu}{\sigma_k}\left(\bar{\rho}S_T\sqrt{K}\tilde{R}_{ij,k}\right)_{,k}-C_{r3}\bar{\rho}\frac{\sqrt{K}}{S_D}\left(\tilde{R}_{ij}-\frac{1}{3}\tilde{R}_{kk}\delta_{ij}\right)$$
$$-C_{r1}\left[a_i\bar{P}_{,j}+a_j\bar{P}_{,i}\right]+C_{r2}\bar{\rho}\left[\tilde{R}_{ik}\tilde{u}_{j,k}+\tilde{R}_{jk}\tilde{u}_{i,k}\right]-C_{r2}\frac{2}{3}\bar{\rho}\tilde{R}_{mk}\tilde{u}_{m,k}\delta_{ij}+C_{r1}\frac{2}{3}a_k\bar{P}_{,k}\delta_{ij}-\bar{\rho}\frac{2}{3}\frac{K^{3/2}}{S_D}\delta_{ij}$$

Turbulent Mass Flux Transport

$$\boxed{a_i\equiv-\overline{u_i''}=\overline{\rho' u_i'}/\bar{\rho}}$$

$$\frac{\partial\left(\bar{\rho}a_i\right)}{\partial t}+\left(\bar{\rho}\tilde{u}_k a_i\right)_{,k}=b\bar{P}_{,i}-\tilde{R}_{ik}\bar{\rho}_{,k}-\bar{\rho}a_k\bar{u}_{i,k}+\bar{\rho}\left(a_k a_i\right)_{,k}$$
$$+\bar{\rho}\frac{C_\mu}{\sigma_a}\left(S_T\sqrt{K}a_{i,k}\right)_{,k}-C_{ap}b\bar{P}_{,i}+C_{au}\bar{\rho}a_k\bar{u}_{i,k}-C_{a1}\bar{\rho}\frac{\sqrt{K}}{S_D}a_i$$

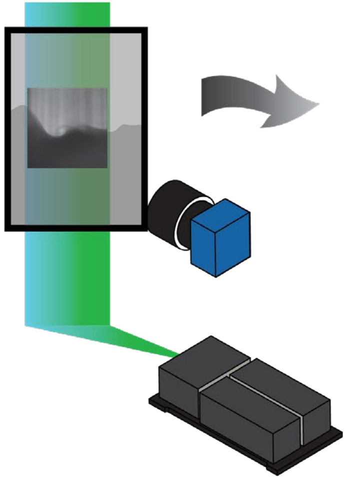
Density-Specific Volume correlation

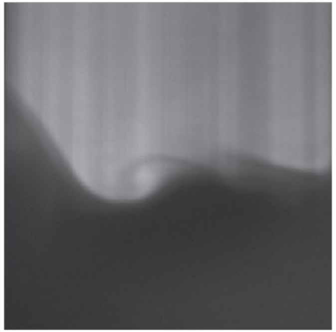
$$\boxed{b=-\overline{\rho'(1/\rho)'}}$$

$$\frac{\partial\left(\bar{\rho}b\right)}{\partial t}+\left(\bar{\rho}b\tilde{u}_k\right)_{,k}=-2\left(b+1\right)a_k\bar{\rho}_{,k}+2\bar{\rho}a_k b_{,k}+\bar{\rho}^2\frac{C_\mu}{\sigma_b}\left(\frac{1}{\bar{\rho}}S_T\sqrt{K}b_{,k}\right)_{,k}-C_{b1}\bar{\rho}\frac{\sqrt{K}}{S_D}b$$

Schwarzkopf, Livescu, Gore, Rauenzahn, Ristorcelli (2011) *J. Turbulence*

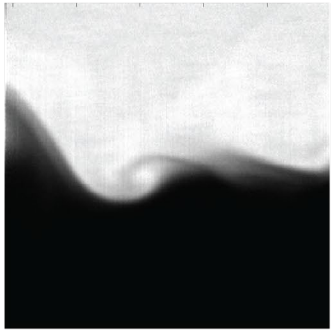
Planar laser induced fluorescence (PLIF) uses a calibrated intensity signal to measure concentration and density fields





$$I/I_o = e^{-\sigma \int N dz}$$

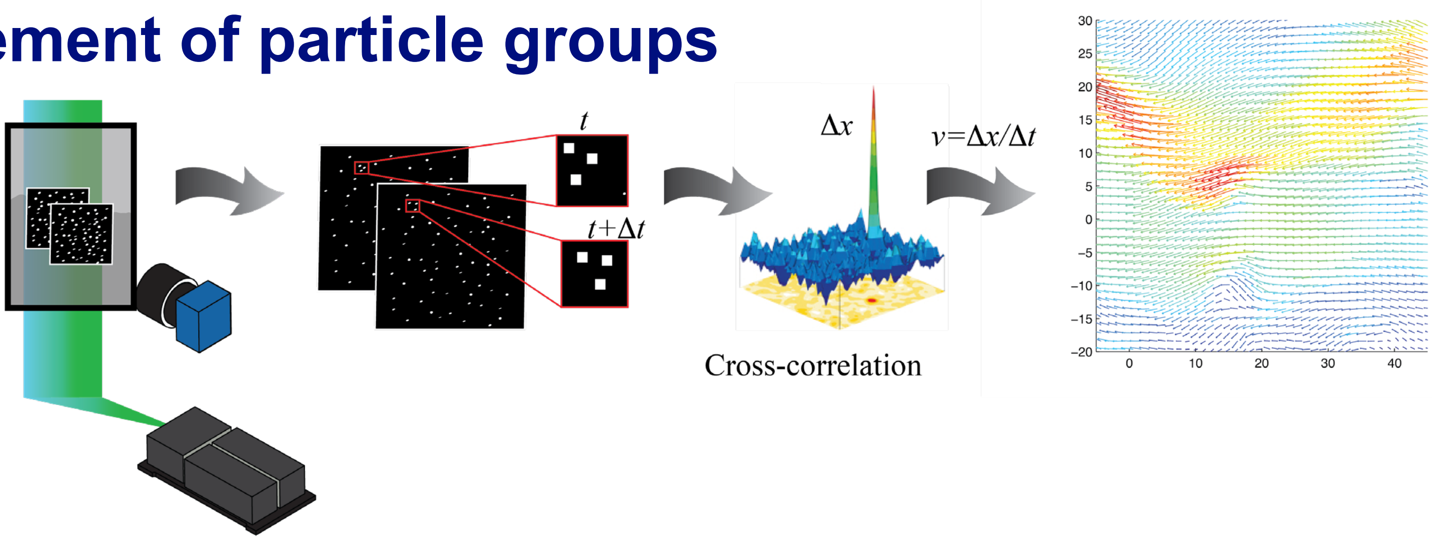
Correct for laser attenuation



$$\rho \propto c \propto I$$

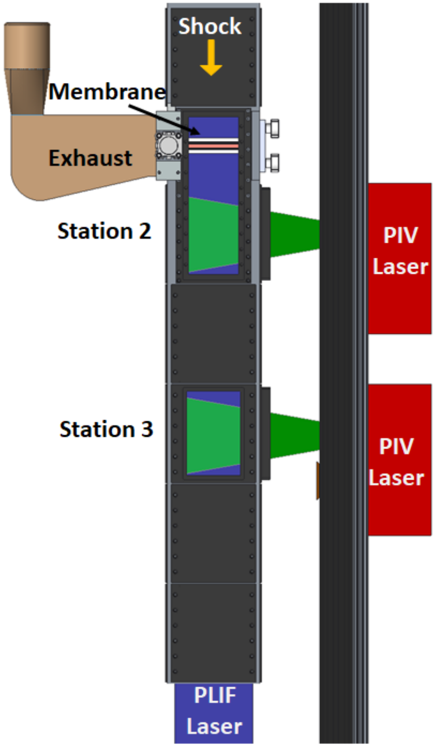
- **Using optics laser light transformed into thin sheet (~ 1 mm thickness)**
- **Acetone tracer fluorescence centered at 405nm when excited by 266nm light.**
- **Fluorescence intensity is proportional to acetone concentration, allowing us to calibrate images to density**

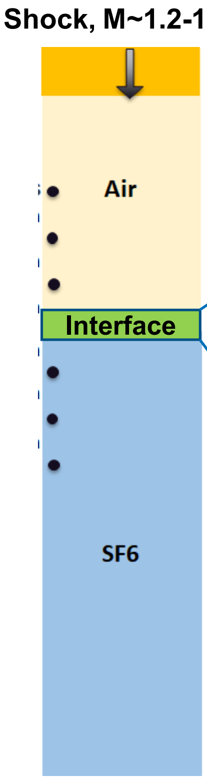
Particle image velocimetry (PIV) uses correlation to track the displacement of particle groups

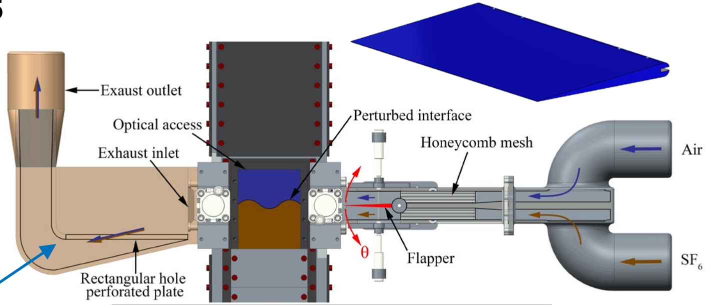


- **Using optics laser light transformed into thin sheet (~ 1 mm thickness)**
- **Droplet tracers (such as olive oil ~ 1 µm Ø) follow the flow field**
- **Illuminated particle positions imaged by dual frame camera.**
- **Average displacement of particles found by correlation.**
- **Local velocity calculated from local displacement and time interval between images**

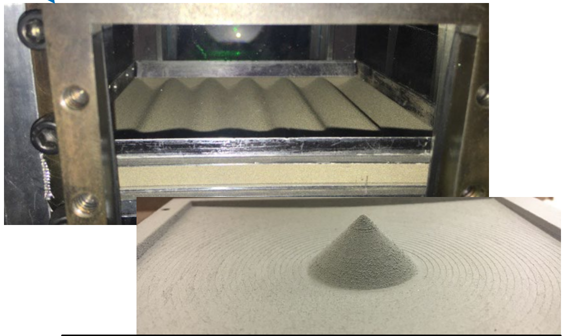
The Vertical shock tube studies the effect of initial conditions on variable-density mixing under shock-driven conditions



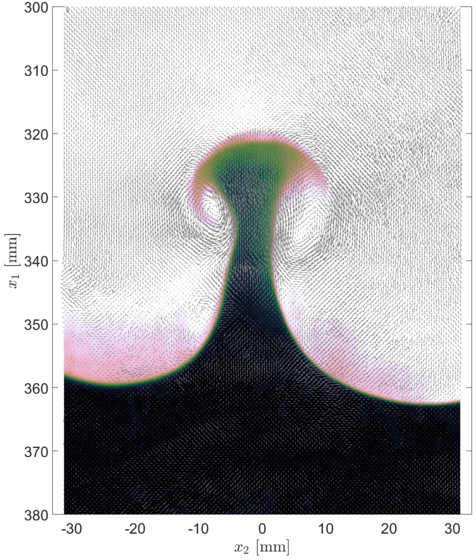




Perturbing cross flowing gases generates repeatable initial conditions, but profile shape is limited



3D printed membranes allow us to study complicated, deterministic geometries but can affect the flow and diagnostics



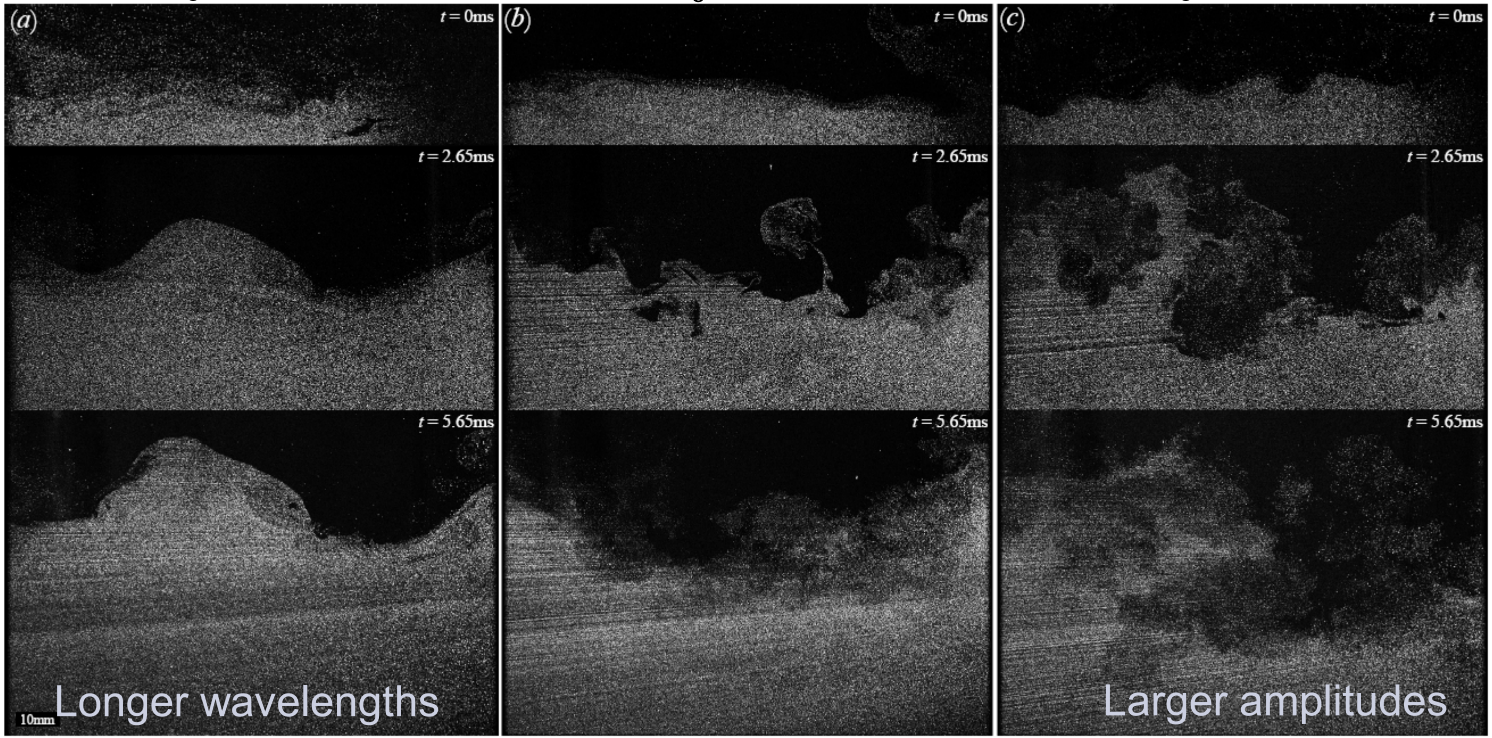
We found that increasing the perturbation frequency and amplitude of the initial conditions creates an earlier mixing transition

$\overline{ka_0} = 0.30$ $\overline{ka_0} = 0.53$ $\overline{ka_0} = 0.86$

t = 0 ms

t = 2.65 ms

t = 5.65 ms

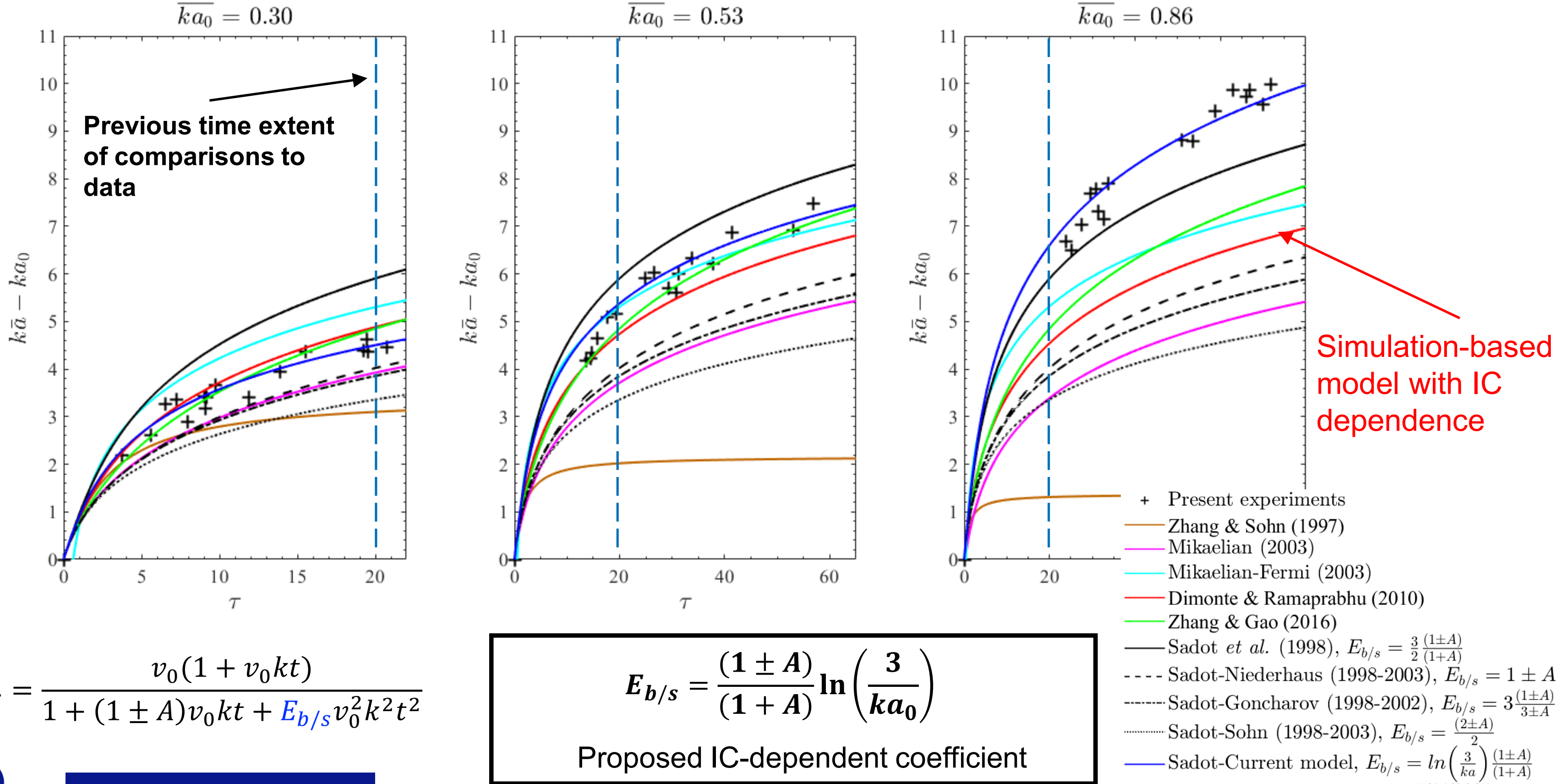


$\overline{\lambda_0}$(mm)
29.1 ± 3.7
19.7 ± 1.8
18.3 ± 1.1

$\overline{a_0}$(mm)
1.37 ± 0.17
1.65 ± 0.18
2.51 ± 0.15

Mansoor, M. M., *et al.* J. Fluid Mech. 904 (2020)

We also found that we need to add a ka_0 dependence to the asymptotic component to match our experimental results



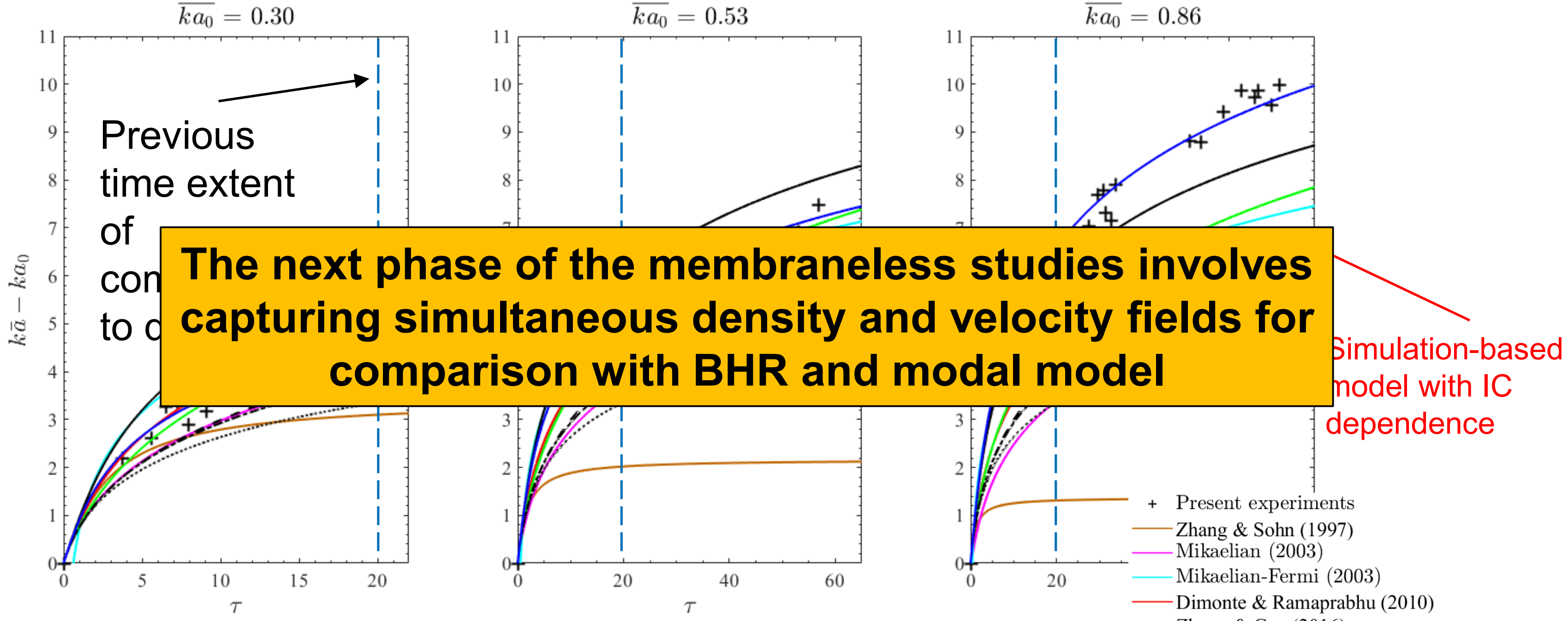
$$v_{b/s} = \frac{v_0(1 + v_0 kt)}{1 + (1 \pm A)v_0 kt + E_{b/s} v_0^2 k^2 t^2}$$

$$E_{b/s} = \frac{(1 \pm A)}{(1 + A)} \ln\left(\frac{3}{ka_0}\right)$$

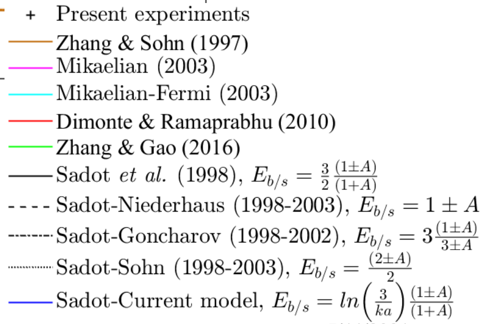
Proposed IC-dependent coefficient

Mansoor, M. M., *et al.* J. Fluid Mech. 904 (2020)

We also found that we need to add a ka_0 dependence to the asymptotic component to match our experimental results



The next phase of the membraneless studies involves capturing simultaneous density and velocity fields for comparison with BHR and modal model



$$v_{b/s} = \frac{v_0(1 + v_0 kt)}{1 + (1 \pm A)v_0 kt + E_{b/s} v_0^2 k^2 t^2}$$

$$E_{b/s} = \frac{(1 \pm A)}{(1 + A)} \ln\left(\frac{3}{ka_0}\right)$$

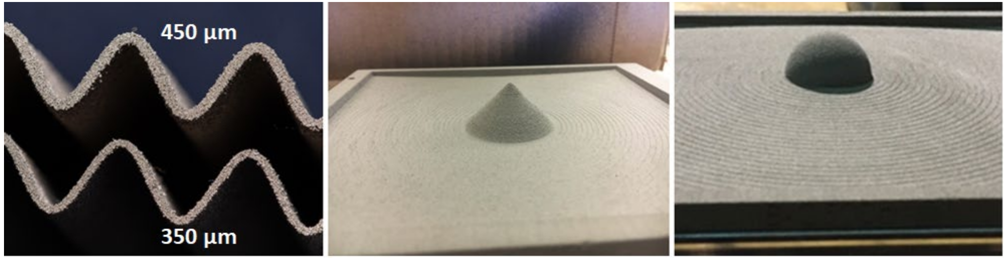
Proposed IC-dependent coefficient

Mansoor, M. M., *et al.* J. Fluid Mech. 904 (2020)

We are pursuing methods of generating deterministic complex initial conditions

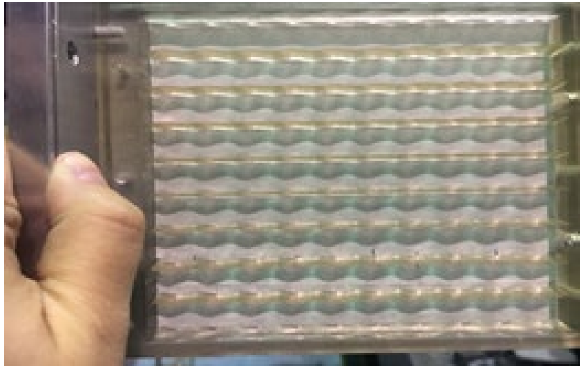
Binder Jet:

Particle beds bounds together with binder



Frames with fragile inner materials such as:

- Phylo dough
- Thin aluminum foil (0.9 um and 2 um?)
- Mylar



SLA:

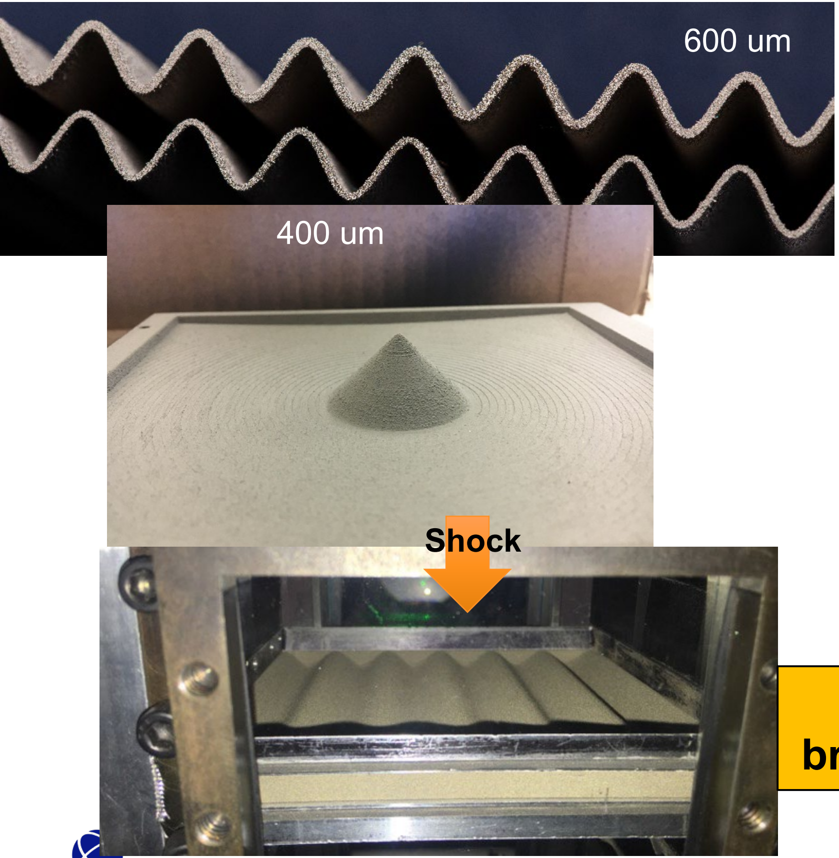
Resin vat hardened by laser

FDM:

Materials heated and layered in semi-liquid state

Majority of materials break poorly and reflections cause saturation of diagnostics

Binder jet membranes showed the most promise, are comprised of small (~30 μm) stainless steel particles



Advantages:

- Complex shapes
- In a green state, very fragile
- Minimal effect on diagnostics

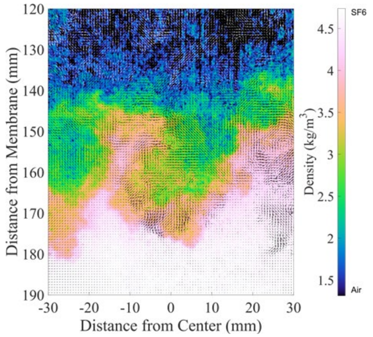
Disadvantages:

- 3D printing is not very precise, defects occur, membranes may not break reproducibly
- Particles are still large, and break into larger pieces
- Some pieces do flow with into optical view and degrade diagnostics
- In a green state, very fragile

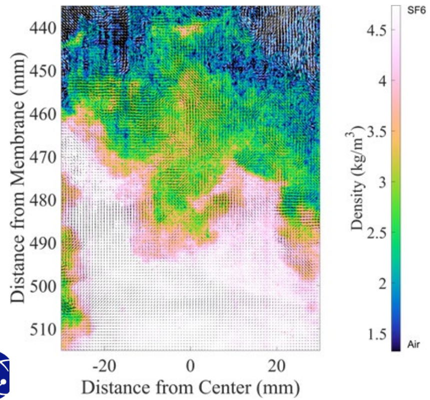
Preliminary shots showed promising results, but breakup was found to be dependent on profile shape

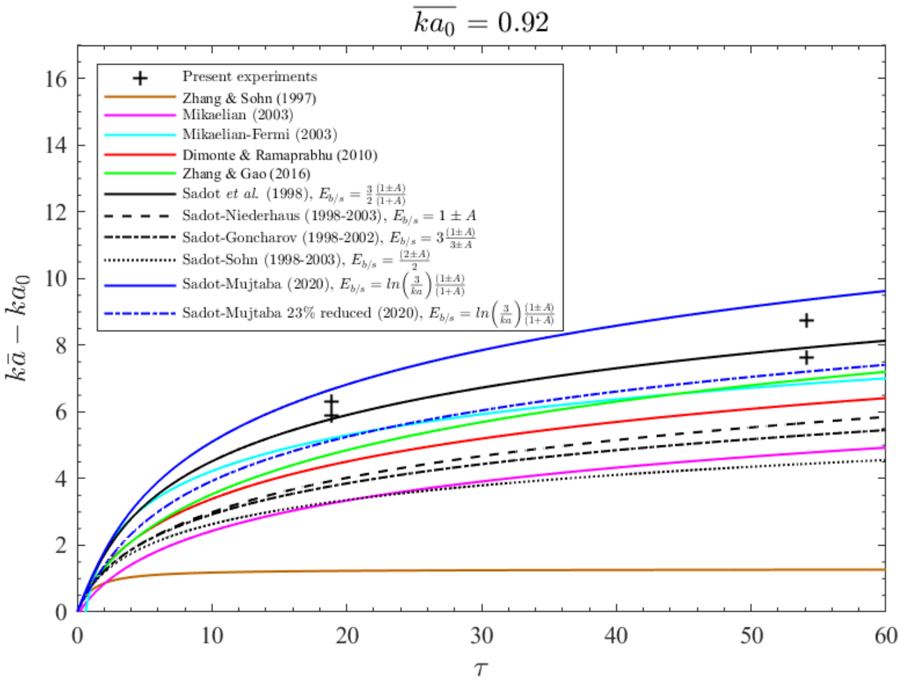
Initial tests with ka_0 = 0.92 show large spike and bubble growth, and comparison with analytical models showed growth rate matched expectations

Station 2 (t~1600 us)

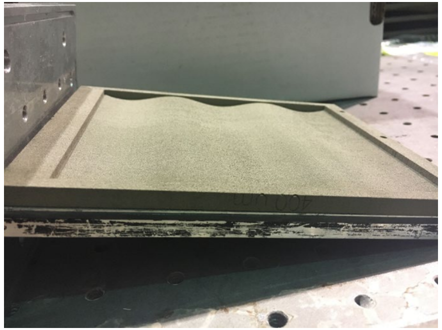


Station 3 (t~4600 us)

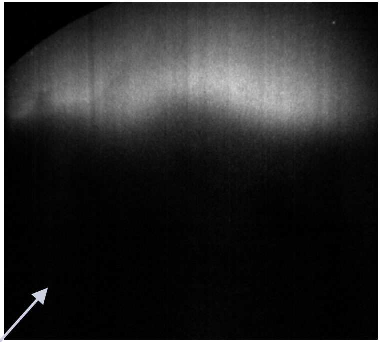




However, when we moved to ka = 0.24, with smaller amplitudes and longer wavelengths…



Station 2

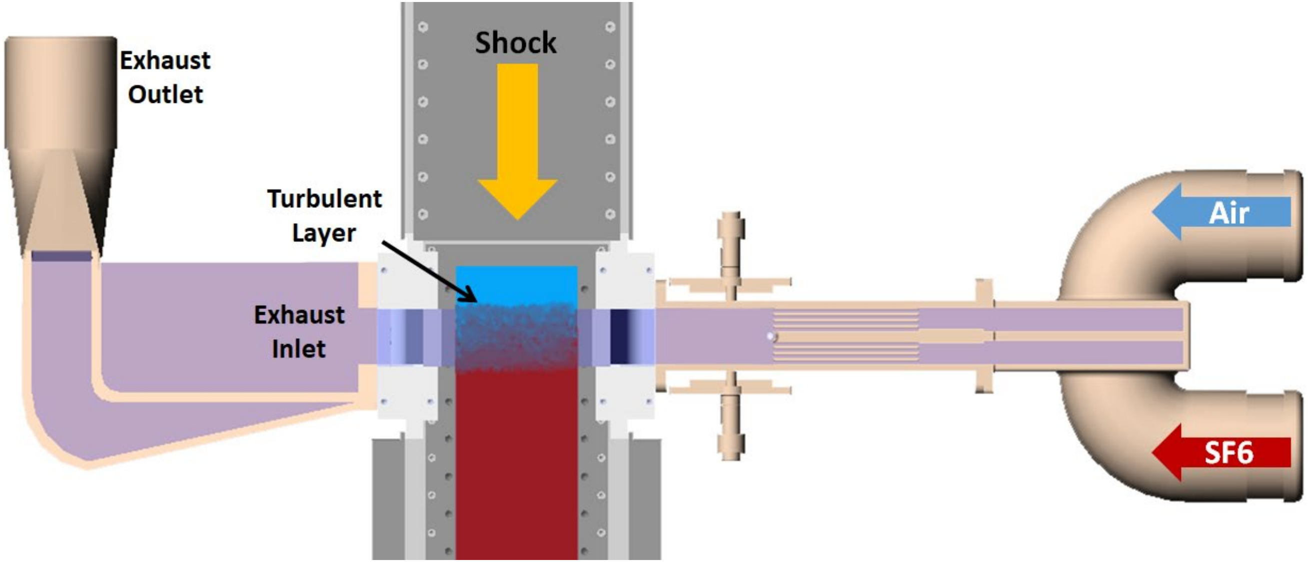


Station 2 looks 'clean'
Station 3 is broken up

Station 3

Long-wavelength membranes are breaking into larger pieces!

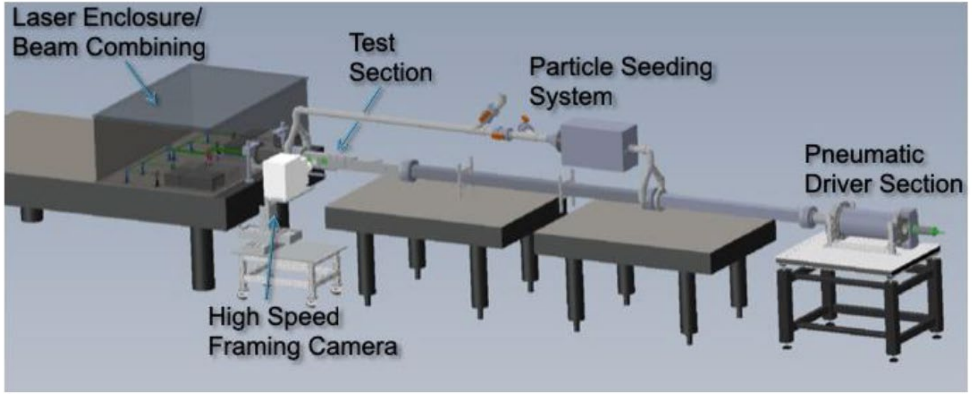
The VST is beginning work on studying shock-turbulence interactions in a variable-density setting



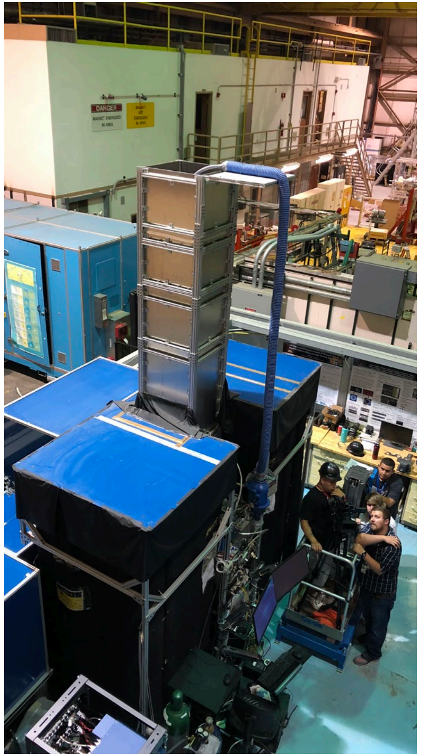
20210601ECR: Shocked Variable-Density Turbulence

DNS simulations have studied this problem under limited conditions
Experiments will be able to study regimes DNS cannot reach

Besides initial conditions, we also study particle drag and steady-state variable density turbulence…

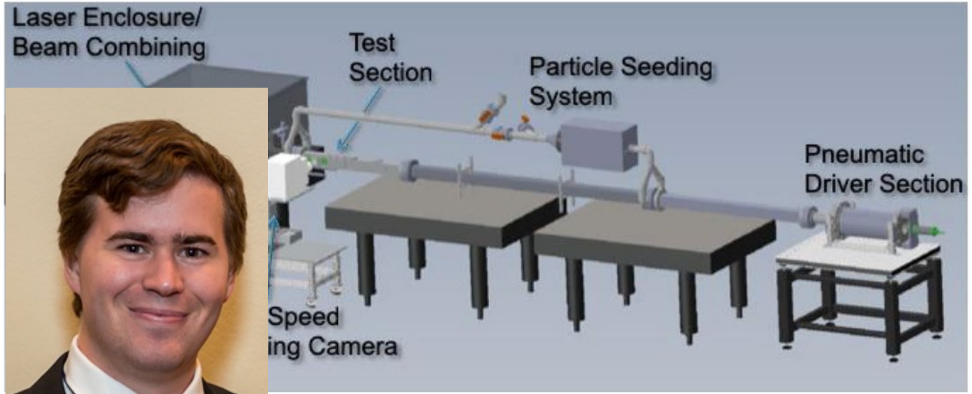


Horizontal Shock Tube (HST)

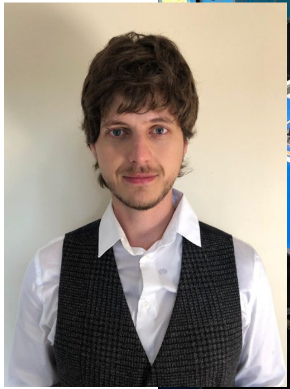


Turbulent Mixing Tunnel (TMT)

Besides initial conditions, we also study particle drag and steady-state variable density turbulence…



Horizontal Shock Tube
(HST)



Turbulent Mixing Tunnel
(TMT)

Thank you!